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Micrometrical Measures of the Ball and Ring System of the Planet Saturn, and Measures of the Diameter of his Satellite Titan, made with the 36-*inch Refractor of the Lick Observatory in the year* 1895. *With some Remarks on Large and Small Telescopes.* By E. E. Barnard, M.A.

In *Monthly Notices* for 1895 May I have given a series of measures of the ball and ring system of the planet *Saturn*, made with the 36-inch refractor of the Lick Observatory during the opposition of 1894.

In the following opposition of 1895 these measures were repeated with the same instrument, so that the final result should rest upon two years' observations. These last measures, reduced to the mean distance of *Saturn* from the Sun, are here given. It will be seen that in the main they are accordant with the results of 1894.

In the opposition of 1894 no direct measures were made of the inner diameter of the crape ring; its diameter, however, was deduced from the measures of the other elements. During the past opposition of 1895 this ring was measured directly, and the present value for its diameter is to be adopted.

In all the measures the utmost care was taken to determine the apparent elements without prejudice from the previous work. As I have previously stated, the objects measured were carefully bisected with the middle of the wire in each case. As the wires are only about 0″·1 in thickness, this could be done with considerable precision.

So far as the surface markings were concerned, no new objects were seen. Much discussion has arisen over the apparently

abnormal lack of details shown in my previous observations of *Saturn* with the 36-inch. From this fact, and other considerations, the general impression seems to be that, from various causes, great telescopes are inferior to smaller ones for showing the delicate markings on the surface of a planet. I think this is a false impression, and does an injustice to great telescopes in general.

I shall not try to explain why the numerous details reported to have been seen on some of the planets with very small telescopes have not been verified with the great telescope on Mount Hamilton. Let it be sufficient, however, for me to say that my faith in the ability of this great instrument to show anything that can be seen in a smaller telescope has never been shaken.

At the opposition of *Saturn* in 1895, as on all previous occasions, no spots were seen upon the planet with any aperture, either in early twilight, at dawn, or after dark.

It is well to state here that all the measures and observations that I have made with the great telescope have been with the full aperture, except on the two following occasions.

To test the effect of reduction of aperture on the visibility of markings on *Saturn*, the following experiments were made :—

On 1895 July 14 the aperture was reduced by a diaphragm to 12 inches. *Venus* was first tried with this, but no definite markings were seen. The image was, of course, duller and steadier. I have on many occasions seen markings on this planet, but they have always been so extremely vague and ill-defined that nothing definite could be made of them.

These were noticed on this last occasion with the full aperture and also with the aperture reduced, but they were not seen any better with the smaller aperture, though one might expect, under some conditions, an improvement in the case of *Venus* by reducing the aperture. On this evening *Saturn* was also examined with both the full and reduced apertures. With the 12 inches the image was steadier, but no indication of additional markings could be made out. With the diaphragm removed the image was much brighter and everything was better seen.

The same experiment was tried on July 15, and the following notes were made :—

"1895 July 15.—At 7^h 45^m observed *Saturn* with the 36-inch. Seeing = 4 (5 perfect). High west wind, but not striking the telescope. After carefully examining the planet [with full aperture] put a 12-inch diaphragm over the O.G. The image was then of a dull yellow, but the details were not so distinct as with the full aperture. No abnormal features could be seen. The view was more satisfactory without the diaphragm. Magnifying powers of 350 and 520 were used. With the full aperture the narrow dusky belt at the equator was distinct, as was also the small dark north polar cap. These were not so distinct with the 12-inch aperture, though they were seen fairly well with it."

These experiments were carefully made to satisfy the desire that seems to exist in the minds of a number of astronomers to know if a reduction of the aperture of this great telescope would make it show planetary markings that were not visible with the full aperture. From these experiments, and from others that I have made in this direction with smaller telescopes, I am convinced that everything that can be seen with this telescope diaphragmed down can be seen with the full aperture, and furthermore, such can be better seen with the full aperture when the air is steady. If the object is very bright, or the air unsteady, I think a reduction of aperture would be an improvement. But, as I have said previously (*Monthly Notices* for 1895 May), it is better to reduce the light by a cap, with a small hole in it, placed over the eyepiece.

In concluding the subject of reduced apertures, I would give it as my opinion that, whatever value small apertures may seem to have for seeing faint planetary markings in the hands of other observers, for my own part a large telescope, if the air is steady, is much better for planetary and other visual work. For diffused and large nebulæ—for contrast—a small telescope is always better than a large one.

It has always appeared to me, when I have heard large telescopes decried in this connection, that if these same observers could look at *Saturn* or *Jupiter* with a great telescope, under first-class conditions, they would themselves be astonished at the difference, and would at once decide for the larger aperture. Until one has used a large telescope under good conditions he can form no sort of idea as to the real appearance of one of the celestial bodies in such a telescope as that on Mount Hamilton. I have used both small and large telescopes, and can appreciate the full value of my statement. If the seeing, however, is bad or very indifferent, I would prefer the smaller telescope.

My drawing of *Saturn* in *Monthly Notices* for 1895 May has not been correctly reproduced. The crape ring has been made entirely too light; the original drawing showed but little contrast between this ring and the sky. My statements about the crape ring in that paper refer only to the original drawing, and in no way to the reproduction.

There is one question that may naturally arise in speaking about the visibility or invisibility of planetary markings in a great telescope. In failing to verify certain things shown on drawings with small glasses, does a large telescope show anything not shown on these drawings? If not, it would rather speak in favour of the smaller instrument for such work. A few remarks on this subject may not be out of place in this paper. I shall speak from a personal experience.

So far as *Jupiter* is concerned, I have paid great attention to this planet for the past fifteen years, and have carefully observed and drawn it with all sized telescopes, from the smallest to the largest. I must say that with all the smaller telescopes the

details on *Jupiter* have been very much inferior to those seen with the 36-inch. Even with the fine 12-inch of the Lick Observatory the view of this planet's surface is very much inferior to that given by the great telescope. I mean by this that there are finer details seen in the 36-inch, and that all the details seen in the 12-inch are clearer and better seen in the large telescope. The view of this splendid planet, with this noble instrument, under first-class conditions, is magnificent, and the amount and intricacy of detail is utterly beyond the ability of an observer to depict. But since these are always changing, and comparisons of observations of this planet at different times are not strictly possible, let us take another object—*Mars*—where there seems to be at least an appearance of stability. I have carefully observed, drawn, and measured the surface markings of this planet with the 36-inch during the past two oppositions. I have also examined a great many drawings made of it with all kinds of telescopes, and must confess that I have been amazed at some of the details shown on many of these drawings. I must confess also that in many respects it seems proved, if we are to take the testimony of the drawings themselves, that the smaller the telescope the more peculiar and abundant are the Martian details.

In the past opposition of 1894, *Mars*, when on the meridian, had a high altitude, and was extremely favourably placed for observing with the 36-inch.

On several occasions during that summer, principally when the planet was on the meridian shortly after sunrise—at which time the conditions for good seeing are often exceptionally fine at Mount Hamilton—its surface with the great telescope has shown a wonderful clearness and amount of detail. This detail, however, was so intricate, small, and abundant, that it baffled all attempts to properly delineate it. Though much detail was shown on the bright "continental" regions, the greater amount was visible on the so-called "seas." Under the best conditions these dark regions, which are always shown with smaller telescopes as of nearly uniform shade, broke up into a vast amount of very fine details. I hardly know how to describe the appearance of these "seas" under these conditions. To those, however, who have looked down upon a mountainous country from a considerable elevation, perhaps some conception of the appearance presented by these dark regions may be had. From what I know of the appearance of the country about Mount Hamilton as seen from the observatory, I can imagine that, as viewed from a very great elevation, this region, broken by canyon and slope and ridge, would look just like the surface of these Martian "seas." During these observations the impression seemed to force itself upon me that I was actually looking down from a great altitude upon just such a surface as that in which our observatory was placed. At these times there was no suggestion that the view was one of far-away seas and oceans, but exactly the reverse. Especially was I struck with this appearance in the great

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"ocean" region of the Hour-glass Sea, and especially in the equatorial portion of this region. These views were extremely suggestive and impressive. I have not seen these small and delicate details described elsewhere, and I feel confident they would scarcely be shown in a much smaller telescope. The details shown on the "continental" regions were usually irregular features, principally delicate differences of shade. No straight hard sharp lines were seen on these surfaces, such as have been shown in the average drawings of recent years. I would mention specially the region of the Solis Lacus and following it. Some short diffused hazy lines—rather irregular—were also seen here, running between several of the small very black spots that abound in this region. On several dates—principally about September 30—two long hazy parallel streamers were seen running from the preceding end of the "Cimmerian Sea" towards the north following.

These, however, are details that will be treated of specially when my work upon *Mars* is published. They are presented here simply to show that the views with the great telescope have in nowise been deficient in important details.

Equatorial Diameter of Saturn.

1895.	Measured.	Reduced to MΔ.
	″	″
Mar. 4	18·43	17·58
10	18·37	17·96
Apr. 7	19·17	17·75
14	19·41	17·92
May 6	19·12	17·68
12	19 23	17·84
June 17	18·73	18·08
July 1	18·25	17·99
8	18·08	18·c3
	Mean	17·875

These are corrected for phase by Marth's ephemeris.

Polar Diameter of Saturn.

1895.	Measured.	Reduced to MΔ.
	″	″
Mar. 4	17·12	16·43
10	17·01	16·18
Apr. 14	17·69	16·33
May 6	17·56	16·23
12	17·56	16·29
July 1	16·63	16·39
8	16·43	16·39
	Mean	16·320

Correcting this value for the inclination of the axis towards us we have

Corrected Polar Diameter = 16″·143.

Outer Diameter of Outer Ring.

1895.	Measured. ″	Reduced to MΔ. ″
Mar. 4	41·97	40·28
10	42·12	40·06
24	43·25	40·48
Apr. 7	43·26	40·06
8	43·09	39·92
14	43·36	40·03
15	43·62	40·27
May 6	43·22	39·96
12	43·14	40·01
June 10	42·04	40·14
17	42·05	40·59
24	40·85	39·88
July 1	40·76	40·18
7	40·12	39·95
8	40·29	40·19
	Mean	40·013

Diameter Middle of Cassini's Division.

1895.	Measured. ″	Reduced to MΔ. ″
Mar. 4	36·03	34·58
10	36·24	34·47
24	37·08	34·70
Apr. 7	37·19	34·44
8	37·27	34·53
14	37·41	34·54
21	37·48	34·56
May 6	37·39	34·55
12	37·52	34·80
17	36·29	35·03
24	35·45	34·61
July 1	35·21	34·71
7	34·67	34·52
8	34·55	34·46
	Mean	34·607

With these measures of the diameter of the Cassini division and the measured width of that division, we have for the outer diameter of inner ring

$$34''\cdot135.$$

And for the inner diameter of the outer ring

$$35''\cdot079.$$

Inner Diameter of Inner Bright Ring.

1895.	Measured.	Reduced to MΔ.
	"	"
Mar. 4	26·85	25·77
10	26·99	25·67
24	27·22	25·47
Apr. 7	27·69	25·64
8	27·49	25·47
14	27·83	25·69
21	27·77	25·60
May 6	27·94	25·83
June 17	26·75	25·82
24	26·44	25·81
July 1	26·18	25·81
7	25·58	25·47
8	25·65	25·58
	Mean	25·664

Inner Diameter of Crape Ring.

1895.	Measured.	Reduced to MΔ.
	"	"
Mar. 4	21·36	20·50
10	21·57	20·51
24	21·69	20·30
Apr. 7	22·32	20·67
8	21·97	20·36
14	22·73	20·98
21	22·23	20·50
May 12	22·38	20·76
June 17	21·19	20·46
24	20·87	20·38
July	20·68	20·39
	Mean	20·528

Width of Crape Ring.

1895.	Preceding. Measured.	Preceding. Red. MΔ.	Following. Measured.	Following. Red. MΔ.
Apr. 22	2″70	2″49	2″65	2″45

Width of Cassini's Division.

1895.	Measured.	Reduced to MΔ.
Mar. 4	0″37	0″35
10	0·60	0·57
Apr. 22	0·56	0·52
May 12	0·46	0·42
June 24	0·51	0·50
	Mean	0·472

Measures of the distance from the centre of the Cassini Division to nearest limb of Planet.

1895.	Preceding. Measured.	Preceding. MΔ.	Following. Measured.	Following. MΔ.
Feb. 4	8″13	8″16	8″18	8″21
5	8·19	8·20	8·12	8·13
18	8·52	8·35	8·44	8·27
Mar. 3	8·67	8·33	8·78	8·44
	Mean	8·259	Mean	8·267

The values for the "preceding" have been corrected for the phase of the ball. I have called attention to the fact (*Monthly Notices*, 1895 May, p. 381) that these measures and the others seem to show that the ball is symmetrically placed in the rings.

Collecting the measures for the year 1895, we have the following values for the dimensions of *Saturn's* ring system.

Equatorial diameter of Saturn	17″875
Polar diameter of Saturn	16·143
Outer diameter of Outer Ring	40·013
Inner diameter of Outer Ring	35·079
Centre of Cassini Division	34·607
Outer diameter of Inner Ring	34·135
Inner diameter of Inner Ring	25·664
Inner diameter of Crape Ring	20·528
Width of Cassini Division	0·472

To represent the results of the two years' measures of the different elements, I have taken the means of the measures of the two sets, giving weight according to the number of observations.

Final Results from the Two Years' Measures. Reduced to Distance = 9·538861

Equatorial diameter of Saturn	17·800″ (21 nights' obs.)
Polar diameter of Saturn	16·241 (19 nights' obs.)
Outer diameter of Outer Ring	40·108 (23 nights' obs.)
Inner diameter of Outer Ring	35·046
Centre of Cassini Division	34·517 (21 nights' obs.)
Outer diameter of Inner Ring	33·988
Inner diameter of Inner Ring	25·647 (19 nights' obs.)
Inner diameter of Crape Ring	20·528 (11 nights' obs.)
Width of Cassini Division	0·529 (15 nights' obs.)

For comparison, these differ from Professor Hall's measures of 1884–87, by the following values, H. – B.

Differences H. – B.

Equatorial diameter of Saturn	–0·08″
Outer diameter of Outer Ring	+0·34
Inner diameter of Outer Ring	–0·10
Centre of Cassini Division	+0·01
Outer diameter of Inner Ring	+0·12
Inner diameter of Inner Ring	+0·10
Inner diameter of Crape Ring	–0·01
Width of Cassini Division	–0·11
Mean difference H. – B.	+0·034

The agreement is as close as could be desired in the work of two observers using different instruments. The large difference in the measures of the outer diameter of the ring is strikingly conspicuous considering the agreement in the other elements, but, taking into account the distance measured, this discrepancy is not very great.

It is possible, however, that this may be a real difference due to some excentricity in the outer part of the ring.

The results for the polar and equatorial diameters give a polar compression of $\frac{1}{11 \cdot 42}$.

By an error, the value of the polar compression in my previous paper (*Monthly Notices*, 1895 May, p. 377) was given as $\frac{1}{11 \cdot 44}$; it should have been $\frac{1}{12 \cdot 35}$.

During the past opposition I also repeated my measures of the diameter of *Titan*. It was seldom the disc could be clearly distinguished, but no measures were made unless the satellite was well seen.

Two sets of measures were made of it on June 3 and June 24 at different times during the measures of the planet.

Diameter of Titan.

1895.	Measured.	Reduced to MΔ.
Mar. 10	0″·68	0″·65
Apr. 14	0·76	0·70
May 12	0·73	0·68
June 3	0·78	0·74
3	0·75	0·71
24	0·56	0·55
24	0·64	0·63
	Mean	0·666

Combining the two years' measures of this satellite, the following results for the diameter of *Titan* at the mean distance of *Saturn* from the Sun :

0″·633

Following are the final results of all my measures of *Saturn*, reduced to English miles—the Sun's mean distance being 92,879,000 miles.

Equatorial diameter of Saturn	76,470 miles.
Polar diameter of Saturn	69,770 „
Outer diameter of Outer Ring	172,310 „
Inner diameter of Outer Ring	150,560 „
Outer diameter of Inner Ring	146,020 „
Inner diameter of Inner Ring	110,200 „
Inner diameter of Crape Ring	88,190 „
Width of Cassini Division	2,270 „
Diameter of Titan	2,720 „

This closes my micrometrical work on *Saturn* and his system.

Kenwood Observatory, Chicago, Ill.
1895 *December* 24.